4

Growth and Decline in Classic Maya Puuc Political Economies

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ABSTRACT

The Classic period Puuc region presents Maya archaeologists with significant challenges. One challenge to interpretation lies in the fact that, despite a form of agro-urban settlement that proved highly resilient in the Maya Lowlands overall, Puuc cities flourished relatively briefly, beginning on a grand scale in the sixth century C.E. and with a halt in major building construction and depopulation in the tenth century C.E. This chapter focuses on analyzing how the Puuc economy depended on sustained economic growth and ultimately suffered its consequences for long-term agro-ecological sustainability. We suggest that an important clue to understanding urban collapse in the Puuc is found by looking at transitions in the net energy gain of the agricultural economy over the long-term. The boom-and-crash character of Puuc economic history follows a series of opportunities, challenges, and problem-solving with varying efficacy for long- and short-term sustainability and resilience. These factors include the highly fertile soils as the main resource; water scarcity as a limiting factor; effective water management as a key solution; and costly social complexity a driving force of agro-economic growth. The diminishing returns on energy invested were consequences of a dependency on economic growth as the supply of the primary resource decreased. The elite segments of polities were unable to adjust to decreasing returns, which led to economic decline and, eventually, organizational collapse. The boom-and-crash character of Puuc settlement suggests a political economy that had locked into dependency on constant growth and failed to adapt to diminishing returns. [Puuc Maya, political economy, agro-ecological sustainability, growth, decline]

Introduction

The broad intellectual intent of this volume is to provide insights into the long- and short-term dynamics of social-ecological interactions "useful" to humanity at large, both today and in the future. These studies are useful in the sense that archaeological work can offer socio-ecological system examples, suggest how people in the past managed resources and dealt with climate variability and related crises, as well as provide background for the economic decision-making that has compromised or set the stage for subsequent generations to manage the resources available to them. Investigating the resilience capacity of past socio-ecological systems expands our understanding of sustainability and gives other scholars, planners, and political decision-makers a broader range of options to consider

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when evaluating sustainability in the contemporary world. Archaeology is now ready for the world—but is the world ready for us?

To Pierre Bourdieu, at least, archaeology must have seemed quite irrelevant to society at large when he argued that "archaeologists . . . are never asked what use they are, what their work is for, who they work for or who needs it" (Bourdieu 1993:27). This view of archaeology as self-absorbed and marginal to current social concerns is largely our challenge when addressing today's social and environmental issues—and in attempting to meaningfully disseminate our research results. Perhaps the embodied conceptualization of the past in Andean cognition (Bengtsson 1998) can provide a source of inspiration for countering the notion of the past as irrelevant and instead encourage the idea that archaeology indeed matters in the present (Sabloff 2008). These ideas are lucidly expressed in the Quechua words *ñawpa*, which signifies that the past is "in front of us" and can be seen and known; and *qhepa*, a term for the future that places it "behind us" where we cannot see it. Such embodiment of time in Andean cognition reverberates within the historical ecological argument that the present is contingent on the past (e.g., Balée 2006; Crumley 1994). Although much has happened over the last couple of decades—especially with regard to the research questions that archaeology poses and to the public's view of archaeology's relevance—the greatest challenge to the discipline remains the need to overcome jargon and better communicate beyond our disciplinary and academic boundaries (see Dawdy 2009; Little 2002, 2007; Little and Shackel 2007; Sabloff 1998, 2008, 2009, 2011, among many others). An important first step is to connect archaeological findings to current issues and to establish a general position that historical ecological cases are not simply idiosyncratic or limited to a specific point in time, but rather that the nature of socio-ecological relations today differ to those of the distant past in degree rather than in kind. A second step is to offer historical narratives—case stories of socio-ecological interactions that are thoroughly based in empirical research—that are meaningful to a broader audience by introducing something profound about the human condition on key issues, such as adjusting to climate change, managing diversity, or building food and water security.

This chapter focuses on analyzing how the economy of the Classic period Puuc region of the northwestern Maya Lowlands (Figure 4.1) depended on sustained economic growth and ultimately suffered its consequences for long-term agro-ecological sustainability. Our work offers a brief historical narrative of a complex series of events and conditions detailing a set of opportunities and challenges dealt with by the ancient Maya, as well as the long- and short-term environmental, economic, and social outcomes of their decisions. The Puuc region is particularly interesting since it presents Maya archaeologists with significant intellectual challenges. One is the contradiction of great regional agricultural potential combined with an archaeological record that indicates large-scale urbanization was comparatively late to develop. Although a few earlier centers are now known (Rivera Dorado 1996; Smyth 1998; Smyth et al. in press), large-scale urbanization did not occur until the end of the Late Classic (ca. C.E. 550–800). Once underway, however, regional population multiplied fast and established numerous urban settlements, making the early Terminal Classic (ca. C.E. 800–900) Puuc one of the most densely populated regions of the Maya Lowlands. Sayil, Uxmal, and Xkipché are some of the best known centers and, where mapping data are available, these cities display a low-density settlement pattern of nodal civic-ceremonial cores with dispersed urban sprawl that cluster into neighborhoods around subsidiary civic-ceremonial areas, similar to elsewhere in the lowlands (e.g., Isendahl 2002; Prem 2003; Sabloff and Tourtellot 1991). To a large extent, this low-density settlement pattern of Maya cities is conditioned by a heavy emphasis on urban agriculture analogous to many early cities in lower latitudes globally; for example, in the ancient Khmer civilization of Southeast Asia (Fletcher 2009, 2012) and among the Aztecs of Highland Mexico (Isendahl and Smith 2013). The most basic component of these settlements—the household farmstead (Dunning 2004)—collectively formed agro-urban landscapes (Isendahl 2012) that provided social and ecological frameworks for significant production of food resources, ranging from subsistence to surplus. We also argue that this settlement system located a host of ecosystem services within cities, provided urban resilience capacity to stress, and was an energy-efficient strategy to produce food in societies that lacked wheeled transport and beasts of burden (Barthel and Isendahl 2013; Isendahl and Smith 2013).

Another challenge to interpretation lies in the fact that, despite a form of settlement that proved highly resilient in the Maya Lowlands overall, Classic Puuc Maya cities flourished relatively briefly, with a halt in major building construction and depopulation beginning in the tenth century C.E. We suggest that an important clue to understanding urban collapse in the Puuc is found by looking at transitions in the net energy gain of the agricultural economy over the long-term (Allen et al. 2003; Tainter et al. 2003). In the narrative of the Puuc that we propose, the boom-and-bust—or perhaps boom-and-crash—economic history of the Puuc follows a series of opportunities, challenges, and problem-solving with varying efficacy for long- and short-term sustainability and resilience. The following step-by-step factors were critical to the Puuc narrative: (1) highly

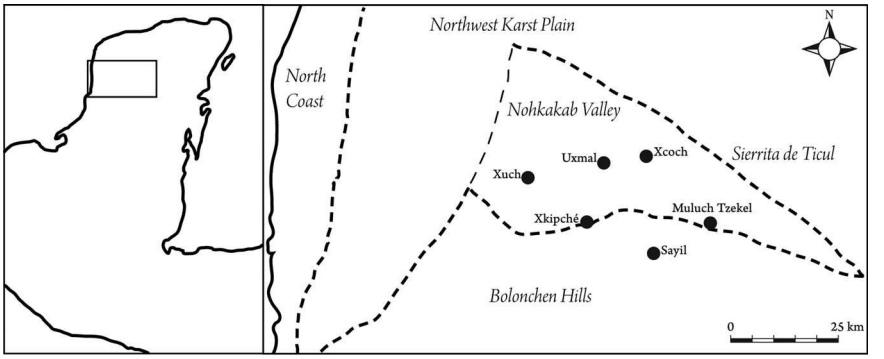

Figure 4.1. Map of the Puuc region on the northwest Yucatán Peninsula, with Classic period Puuc cities mentioned in the text and physiographic districts as described by Dunning and Beach (2010) and Isendahl (2011). Map by Christian Isendahl.

fertile soils were the key resource; (2) water scarcity was a limiting factor; (3) effective water management was a key solution; (4) costly social complexity and ceremonialism was a driving force of agro-economic colonization, growth, and maximization; (5) diminishing returns on energy invested were consequences of a dependency on economic growth as the supply of the primary resource, highly productive unused farmland, decreased; (6) the elite segments of polities were unable to adjust to a phase of decreasing returns on investments; (7) which led to economic decline and, eventually, organizational collapse. The boom-and-crash character of Puuc settlement suggests a political economy that had locked into dependency on constant growth and failed to adapt to diminishing returns.

Although our sample size is inadequate for general conclusions about urban sustainability and vulnerability, we suggest that there are leads to be drawn from analyzing how the Classic Puuc Maya socio-ecological system functioned over time. Our work identifies decisive points in the narrative where the system locked into a path, dependent on rigid economic growth that proved unsustainable and eroded system resilience capacity over time. We believe that these are not simply idiosyncratic insights, but assessments applicable to a better understanding of the resilience of complex, contemporary socio-ecological systems.

Energy Regimes and Transitions in Energy Gain

Joseph Tainter and colleagues have adopted and developed a method of socioeconomic analysis from ecological theory and applied it to the analysis of changes in the long-term sustainability of the Roman imperial economy (e.g., Allen et al. 2003; Tainter 1988; Tainter et al. 2003). This approach examines patterns of large-scale social change based on transitions in net energy gain over time and the consequences of such transitions for the sustainability and resilience capacity of social-ecological systems. The orientation offers an overall theoretical framework that can be applied in basic form for a narrative history of Puuc political economies. The critical concept in this scheme is energy gain, or energy returned on energy invested (Hall et al. 1992), and how transitions between phases of high-gain energy returns and low-gain energy returns are dealt with in an economy. In any early complex agricultural society, the basis of economic and political power is the ability to accumulate capital or resources that can ultimately be interpreted as forms of energy, according to Odum's (1996) use of the term. For the purposes of our analysis, we think of political economies as the social processes in which energy was accumulated among certain social segments in a society at the expense of other groups. While the details of Maya political economies are matters of debate (e.g., Masson and Freidel 2002; McAnany 2013; McAnany and Wells 2008), the economic foundation of elite culture was ultimately based on different ways of controlling past solar energy transformed into agricultural produce and human labor. In a competitive agricultural economy, taking control over a readily available and previously under-exploited resource such as areas of highly fertile soils yielded a high return and financed the establishment of central institutions. In Tainter's model, such high-gain phases are usually relatively short in duration because the key resource is at first abundant and concentrated, but then tends to rapidly diminish owing to subsequent inefficient management. A transition from high-gain to low-gain energy returns occurs as the demand for the resource increases (based, for instance, on the effects of an increasing population, costly organizational complexity, or conspicuous consumption); or, it is maintained at a relatively high level at the same time as the primary resource becomes more scarce and requires higher

investment costs to maintain production levels, thus forcing the ratio of energy returns to energy invested to drop. In such low-gain phases, the key resource is usually scarce, dispersed, produces relatively little surplus per capita, and requires efficient management to be sustained. This broad explanatory framework of transitions in energy-gain ratios can be effectively applied to the broad trends of the social and economic history of the Classic period Puuc region.

The Puuc Maya Boom-and-Crash Economy

1. *Highly Fertile Soils were the Key Resource*

The Puuc covers some 3000 square kilometers and comprises a diverse soilscape. Some of the soils that predominate, including large tracts of Nitisols (in the FAO system of soil classification; Alfisols in USDA taxonomy; Buol et al. 2011), are ranked among the best for cultivation on the Yucatán Peninsula (Dunning 1992), as well as in the tropics at large (Driessen et al. 2001), and may have formed a "bread basket" for neighboring areas with poorer soil resources, particularly the northern coastal Karst Plain (Dunning 1992). Indeed, there is some ethnohistoric evidence to indicate that the Classic Puuc Maya thought of the region as *Nohkakab*, "the place of good earth" (Dunning 2008).

2. *Water Scarcity Constituted a Limiting Factor*

Paradoxically, however, while providing good farming soils, the Puuc is highly vulnerable to drought and access to sufficient amounts of freshwater is the main limiting biogeophysical factor for living and farming in the region (e.g., Isendahl 2011). Like much of the Maya Lowlands, the climate is seasonally dry with very low precipitation outside the rainy season that takes place during May to October. Furthermore, during the rainy season, two common anomalies in the rainfall pattern potentially cause distress to local farmers. One is the mid-summer dry spell, which in some extreme years starts in June and may last for about two months. Since farmers in the region plant maize, beans, squash, and many other crops as soon as the rainy season starts, a severe and prolonged dry spell may jeopardize the planting. Moreover, the fractured structure of the limestone bedrock drains surface water to the deep aquifer and there are very few permanent bodies of water, rivers, or streams in many lowland sub-regions (cf. Fedick, this volume). Setting the Puuc apart from many other parts of the northern peninsula, there are no karst water-bearing landforms such as sinkholes (*cenotes*), few deep, water-bearing caves, and the water table is too deep-lying to provide an accessible resource, thus making rain-fed agriculture and the capture and storage of drinking water that was necessary for surviving the dry season even more vulnerable to erratic rainfall (Dunning et al. 2012). Another potential obstacle is the hurricane season during August to October. Hurricanes and tropical storms strike the Yucatán Peninsula on an average of one per year, and the heavy rains and strong winds hurricanes bring may devastate harvests on a very broad scale—and certainly did so occasionally in the prehispanic past (Dunning and Houston 2011). To live and farm in the Puuc involves considerable effort to deal with water scarcity and the Classic-period Puuc Maya managed seasonal water scarcity by using a number of different techniques to collect and store rainwater.

3. *Effective Water Management was an Important Solution*

To cope with water scarcity and take advantage of the valuable soil resources of the land, Puuc residents developed two main hydro-technological inventions: large, open still-water reservoirs (*aguadas*) and small, underground water cisterns (*chultuns*). Aguadas and chultuns captured and stored rainwater for multiple purposes, including household consumption, garden and field pot irrigation, and ritual and ceremonial activities. Small underground water cisterns were constructed in close proximity to household-based residences, commonly in the center of residential patio groups. These formed the main source of freshwater for domestic use in each household, possibly including pot irrigation of kitchen gardens, and were managed by the farmstead dwellers themselves (McAnany 1995; Zapata Peraza 1989). Large, open, still-water reservoirs with the potential to store much greater volumes of freshwater are quite widespread in the Puuc (Figure 4.2; Dunning 2008) and were managed at a higher level in the social-administrative organization. At both the neighborhood and the city or polity leadership level, the organizing principles depended on how groups were situated on the landscape, on the degree of labor investment in fashioning reservoirs from natural depressions in the topography, and on water storage capacities (Dunning 2008; Isendahl 2011; see also Davis-Salazar 2003; Scarborough 1998). Modified from karst depressions, the construction of reservoirs in large tracts of fertile land (indicating their use in pot irrigation) often involved considerable labor investment at most Puuc cities; these features emphasized control of key large-scale land and potential water resources as an important economic and political basis for Puuc polities (Dunning 2008; Isendahl 2011; Dunning et al. in press). These two systems of water collection and storage may have been integrated; water in reservoirs may have been used to replenish household cisterns (Dunning et al. in press), similar to how water from the large *cenote* sinkhole features may have been used at Chichen Itza (Cobos, this volume).

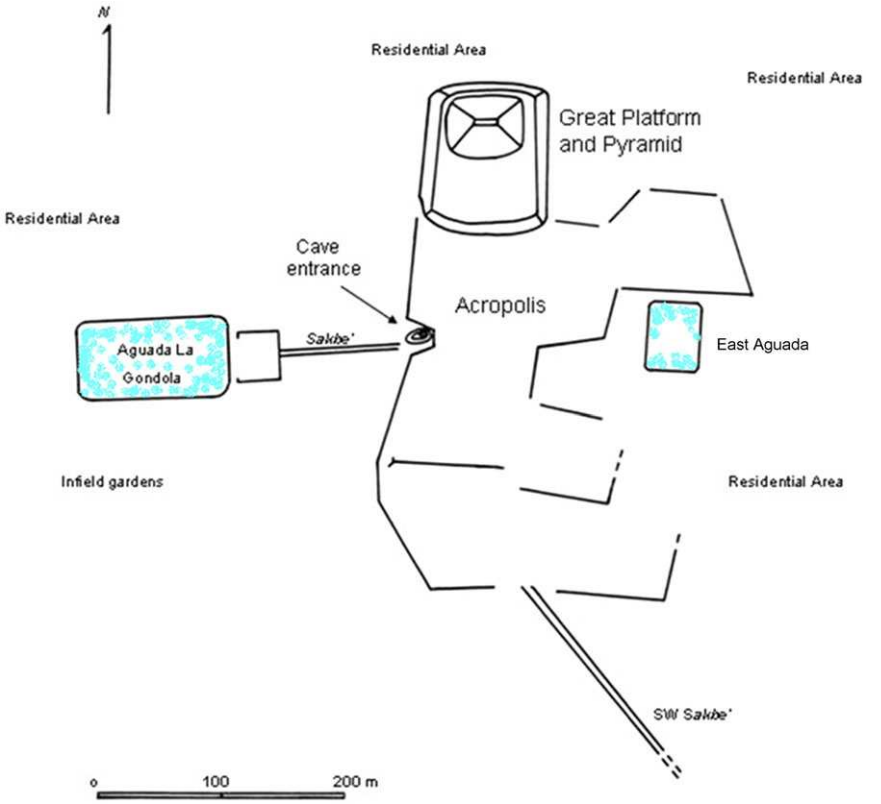

Figure 4.2. The central civic-ceremonial complex at Xcoch showing the location of two large, open, still-water reservoirs (Aguada La Gondola and East Aguada). Map by Nicholas Dunning (adapted from Smyth et al. in press).

Most major Puuc cities are located near large tracts of fertile soil and near geostructural fracturing that increased the frequency of karst depressions, a basic requirement for the construction of large water reservoirs (Dunning 2008; Isendahl 2011). However, it should be noted that not all Puuc cities had large reservoirs, and it remains to be investigated how water was managed at these cities and what consequences the absence of large, open water reservoirs had on their political and subsistence economy.

4. *Costly Social Complexity and Ceremonialism Formed a Driving Force of Agro-Economic Colonization, Growth, and Maximization*

Initial conditions of the Puuc in the sixth century C.E. presented a reserve of under-exploited terrain which, under favorable climatic conditions and efficient water management, formed a great opportunity for highly productive farming in a high-gain phase of energy accumulation. In a competitive agricultural economy, taking control of a readily available and previously un- or under-exploited fertile soil resource yielded a high return on investment and would have financed the rapid establishment of central institutions and their associated urban services and functions in the Puuc. Evidence of conspicuous consumption in the form of Maya monumental architecture and costly ceremonialism suggests that the high-gain phase was accompanied by political integration and economic maximization rather than resilient resource exploitation strategies (see Adams 1978; Alexander 2005). In Tainter's model, high-gain phases are usually relatively short in duration because, while the key resource is initially abundant, it is typically inefficiently managed and rapidly depleted—something that seems partially to be the case in the Puuc region (Andrews 2004; Dunning 1992).

The settlement pattern of the Puuc area was not determined by resource availability alone. Instead, each agro-urban landscape also integrated lower and higher level social institutions. Ethnohistoric documentation of a sixteenth century C.E., four-tiered sociopolitical structure of polity, city, neighborhood, and household (Okoshi Harada 1992; Quezada 1993; Roys 1957) fits very well with Classic period archaeological settlement data (McAnany 1995; Prem and Dunning 2004; Williams-Beck 1998) and offers

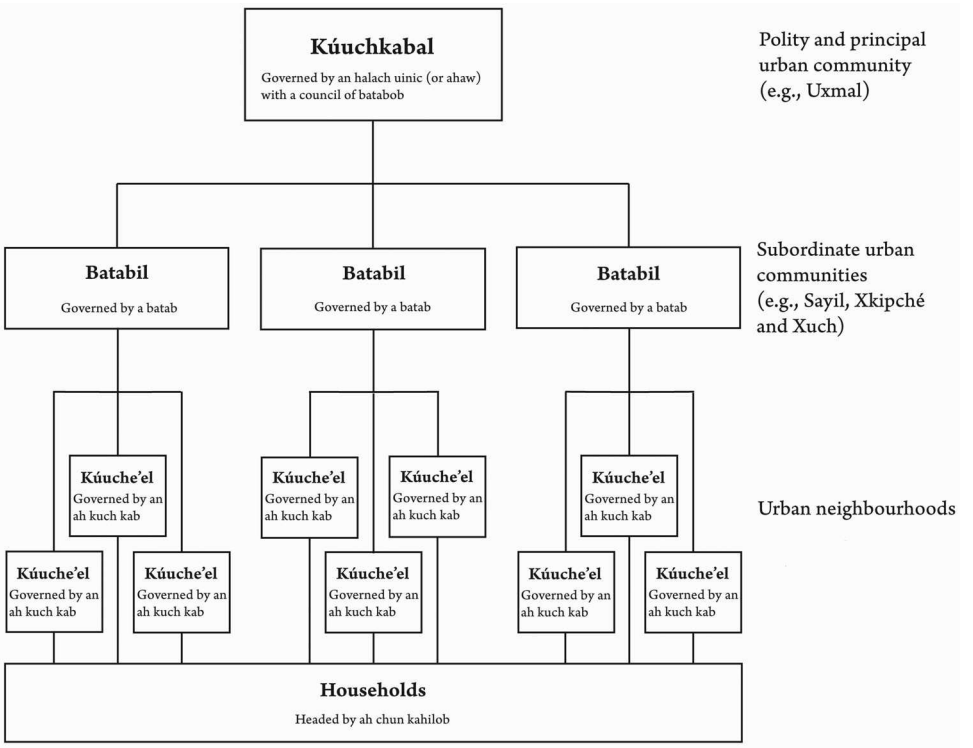

Figure 4.3. Political-settlement hierarchy for Puuc Maya cities. Figure by Christian Isendahl (based on Isendahl 2010:figure 5).

insight as to how resources, in particular farmland and water, were managed and distributed. At the highest level in the hierarchy is the overarching polity (the *kúuchkabal*), a principal settlement governed by a hereditary lord (the *halach uinic* or *ahaw*) and a council of other lords drawn from subordinate cities (Figure 4.3). Uxmal, the largest of the Terminal Classic cities (at least in terms of its presently-known central civic-ceremonial core complex, as urban sprawl at Uxmal has not been adequately investigated), was probably the Puuc capital, or kúuchkabal, in the latter part of the Terminal Classic and possibly before that (Carmean et al. 2004; Ringle and Bey 2001; but cf. Carmean and Sabloff 1996). At the next social-administrative level is a series of subordinate urban communities (*batabilob* [*-ob* is the plural suffix in Yukatek Maya]), each ruled by a *batab* who paid tribute to the ruler of the polity (the *halach uinic*). The batab was the chief executive, judicial, and military officer of each city and ruled over the local city council.

The kúuchkabal was a modular construction of smaller territorial units largely maintained through lineage affiliations of batabob (Quezada 1993). The relatively loose character of such "atomistic polities" indicates that the polity structure likely changed continuously as alliances between and within lineages were renegotiated (Okoshi Harada 1992). Each batabil was divided into several lineage-based neighborhoods (*kúuchte'elob*). Each neighborhood had its own administration, its own subordinate population, and its own lineage head (*ah kuch kab*). The neighborhood and its leadership assumed a central role in the management of natural resources (Isendahl and Smith 2013; McAnany 1995). The lineage head supervised agrarian and commodity production within the *kúuchte'el*, organized agrarian labor, and distributed land and resource rights to household heads (*ah chun kahilob*); he also coordinated and controlled the flow of tribute to the batab. Thus, the urban farming that took place between residential patio groups within neighborhoods and between urban neighborhood clusters in Puuc cities was governed by social interaction and negotiation between different levels in a complex social-administrative organization.

Even if these sociopolitical structures were hierarchically organized in the classic pyramidal sense, recent work on elements of heterarchy in prehispanic social organization suggests that many aspects of the sociopolitical domain of household and communities were socially contested and negotiated—and not simply governed by top-down control (e.g., Scarborough et al. 2003, see also Crumley 1995). The kúuchkabal Puuc polity-model suggests four different kinds of interconnected institutions involved in natural resource management. From the lowest to highest sphere of influence these are the household farmstead, the

neighborhood, the urban community, and the polity; with their own respective forms of leadership and administration, each had its own driving goals and motives and degree of resource connectivity.

As the managing institution most directly connected to the primary food and water resources (Ashmore and Wilk 1988; Wilk 1990), the decisions made by the household farmstead had potential repercussions throughout the system. These were the farmers that tended their gardens, worked the soil and planted, weeded, watered, nurtured, and harvested the plants. We assume here, perhaps simplistically, that the primary goal of the household was to provide dependable sustenance, income security, and other basic human needs for the closest kin. Although we must be careful of anachronistic attribution of current concerns and motivations to people in the past (Smith 2010), each level was likely concerned primarily with its own well-being. However, as we move up the system from lower- to higher-level institutions—from the household to the political leadership of the polity—the immediate connectivity to the primary resource decreases. Higher-level institutions depend on an ability to command the rights to surpluses from lower-level managing institutions—i.e., ultimately farmers' labor and produce. In the Puuc, we argue that such rights were regulated through lineage-based systems of labor and tribute obligations. In Puuc neighborhoods and subsidiary towns and villages, the costs associated with maintaining the kúuchte'el administration (including the construction and maintenance of elite residential buildings and ceremonial buildings, as well as the underwriting large-scale integrative ceremonial events at each kúuchte'el)—as well as the surplus produce and labor obligations the ah kuch kab channeled to the batab and the leadership of the agro-urban community—ultimately burdened the primary producers at the household level. Complex organization is a costly endeavor that needs to be financed in one way or the other (D'Altroy and Earle 1985; Tainter et al. 2003); in agrarian-based prehispanic economies, the products of the farming population were the ultimate source of matter and energy financing complexity. Hence, a lower degree of resource connectivity in higher-level institutions is coupled with elevated political power that is dependent on a costly support system sustained by an expansive farming-sector.

5. *Diminishing Returns on Energy Invested were the Consequences of Long-Term Growth Dependency as the Supply of the Primary Resource—Highly Productive Unused or Under-Used Farmland—Decreased*

Initial conditions of the Puuc region in the sixth century C.E. presented a reserve of un- or under-exploited terrain that, under favorable climatic conditions and efficient water management, formed a great opportunity for highly productive farming in a high-gain phase of energy accumulation. Evidence of conspicuous consumption in the "Monstrous Visual Symbols" (Fletcher 1977; Rathje 2002) of Maya elite residential, civic, and ceremonial monumental architecture suggests that the high-gain energy extraction phase was accompanied by political integration and economic maximization rather than resilient resource exploitation strategies (see Adams 1978; Alexander 2005). For instance, in the Uxmal kúuchkabal at the end of the ninth century C.E., monumental constructions like the House of the Governor and the Nunnery Quadrangle required a huge labor investment to construct (Kowalski and Dunning 1999).

6. *The Elite Segments of Polities were Unable to Adjust to a Low-Gain Energy Phase Transition*

By the end of the tenth century C.E., if not before, cities throughout the Puuc area were depopulated (Braswell et al. 2011; Carmean et al. 2004). Depopulation seems to have extended into the countryside, though this phenomenon has been less studied. Simms et al. (2012) document the rapid abandonment of farmsteads around Kiuic in the Terminal Classic. Peaking energy gain seems to have occurred in the Puuc sometime during the early Terminal Classic, followed by a transition from high-gain to low-gain energy returns as a result of increasing regional population, diminishing available farmland per capita, intensified cropping, and decreasing surplus production, while costly demands to maintain central institutions persisted. Tainter's model suggests that in such low-gain phases the key resource is usually scarce, dispersed, produces little surplus per capita, and requires efficient management that often increases costs. In this view, regional settlement abandonments in the latter half of the Terminal Classic indicate that Puuc kúuchkabalob and batabilob were not resilient to transitions in energy gain. These institutions were unable to make the organizational decisions necessary to manage a transition from a high- to a low-gain mode. Decreasing revenues combined with an inability to finance higher-level institutions prompted an organizational crisis. The boom-and-crash character of Puuc settlement suggests a political economy that had locked into a dependency on sustained growth and failed to adapt to diminishing returns. Indeed, perhaps counter to more economically "sensible" measures, the leadership of Uxmal initiated large-scale monumental building programs in the city that might have been ideologically motivated but that its economy hardly could afford at this point in time—and the city seems to have crashed soon thereafter (see Culbert 1973 and Hosler et al. 1977 for broader discussions of this point for

cities throughout the Maya Lowlands). Here we see a growing conflict between the decentralizing tendencies within Maya agriculture and the statist goals of the Uxmal city and polity leadership—a drama that has repeated itself historically in other contexts (Nair 1979). While the cultural logic of the ancient Maya may have supported the idea of greater investment in deified rulers, it became increasingly inconsistent with the subsistence needs of the society as a whole (McAnany and Gallareta Negrón 2010). This scenario seems to illustrate well the point of resilience theory in that the connectivity to the primary resource decreases as we move up the system from lower- to higher-level institutions—from the household to the political leadership of the city and polity.

7. *Failing to Adapt to Diminishing Returns Led to Economic Decline and Eventually Polity Collapse*

Once the Puuc agricultural system had been pressed into delivering maximum crop yields, the region's soil resources could only sustain such high levels of productivity for a limited time—no more than 75 years before crashing (Andrews 2004). This non-sustainable system likely deteriorated even more catastrophically under the influence of drought induced stresses (Medina Elizade et al. 2010). The Puuc region was doubly vulnerable to drought because both agricultural production and basic water-based sustenance were dependent on the collection and storage of water in adequate quantity and quality. Like other parts of the elevated interior region of the Yucatan Peninsula, urbanization in the Puuc area required a significant "up front" investment in large-scale water management infrastructure such as reservoirs. Once depopulation occurred, revenues significantly dropped and urban hydraulic systems deteriorated; reoccupation would have required a sizable investment to refurbish these systems (Dunning et al. 2012). These resettlement costs may help explain the relative slowness of interior regions like the Puuc to be reoccupied and form large urban settlements after the economic and organizational crises of the Terminal Classic period.

Implications

Archaeological and historical ecological research that offers a synthetic historical narrative of growth dependency and decline in Classic Puuc Maya political economies provides potentially useful information on the challenges and opportunities for building resilience capacity in social-ecological systems over the long-term. We suggest that these insights are relevant for understanding contemporary sustainability concerns in at least three interrelated domains.

1. *A Systemic Dependence on Maximizing Economic Production Limits Options*

The Late and Terminal Classic proliferation of cities and polities in the Puuc represents a period of expanding exploitation of regional agricultural lands or niche filling. As all prime lands were eventually brought into cultivation and political dominion, production intensified to levels that were not sustainable in the long term. Ultimately, outside of technological innovation, which did not occur, the best possible step for continued growth was the capture of neighboring land and labor through military conquest, most notably visible in the rise of the Uxmal kúuchkabal. However, this effort failed under a maximizing management regime in a heavily populated region. The Puuc case highlights that maintaining a diversity of options for spreading risk and planning for diminishing returns are essential strategies for long-term resilience.

2. *Large-Scale Investments in Infrastructure are Long-Term, High-Risk Ventures*

For those Puuc communities that chose to invest in reservoirs, this decision had major economic implications with start-up costs. At places such as Xuch and Muluch Tzekel, berms constructed to enhance the water storage capacity of reservoirs represent among the largest labor investments made in these settlements (Dunning 2008; Isendahl 2011). Maintenance in the form of dredging, re-flooring, and berm heightening represented further investments, such as seen in the huge city center reservoir of Aguada La Gondola at Xcoch and the hinterland Xcoch South Aguada 1 (see Figure 4.2; Dunning et al. in press). While these investments undoubtedly helped reduce water-related risks for a time, long-term risk may have actually increased. The security provided by the reservoirs likely facilitated urban population concentrations, ultimately putting these people at risk as the traditional pattern of a more resilient dispersed settlement was disrupted.

3. *Maintaining a Dynamic Capacity of Social Institutions to Fragmentize and Re-Coalesce Provides Adaptive Capacity to Temporal Oscillations in Economic Returns*

For millennia, the resilient capacity of Maya communities on the Yucatan Peninsula has been at its best when options for population mobility were retained, allowing dispersal in times of environmental stress such as drought. Resilience has been worst when populations have been forcibly

concentrated, such as during the Colonial-era *reducciones* (forced settlement in Spanish towns) that likely contributed to several regional famines (Farriss 1984). In the Terminal Classic Puuc, the concentration of population at Uxmal during a period of intensifying drought likely hastened subsequent regional depopulation. The Puuc Maya cities followed a growth trajectory that was path dependent on maximized management regimes to maintain urban functions and services; this growth proved unsustainable over the long term when key resources were depleted and revenues decreased. However, in the agro-urban landscape, the household-based farmstead garden retained some degree of agro-economic autonomy, upheld farming practices, and preserved and developed agro-ecological pools of knowledge of how to produce food. Thus, these lower-level social institutions maintained resilience capacity over the long-term and provided a potential to reorganize into less complex forms of organization in times of urban crises.

The high risk associated with locking into economic growth for the long-term maintenance of societal functions and ecosystem services, suggested by the historical ecological case of the Puuc, reverberates profoundly in relation to the growth mantra of contemporary globalized economies as well as in mainstream political discourse. Archaeologists are increasingly proficient at inferring the factors that contributed to the resilience of past societies and that introduced vulnerabilities. We argue that these insights can be useful for understanding pathways to sustainable trajectories in the contemporary world.

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